Comparison of plasma breakdown with a carbon and ITER-like wall

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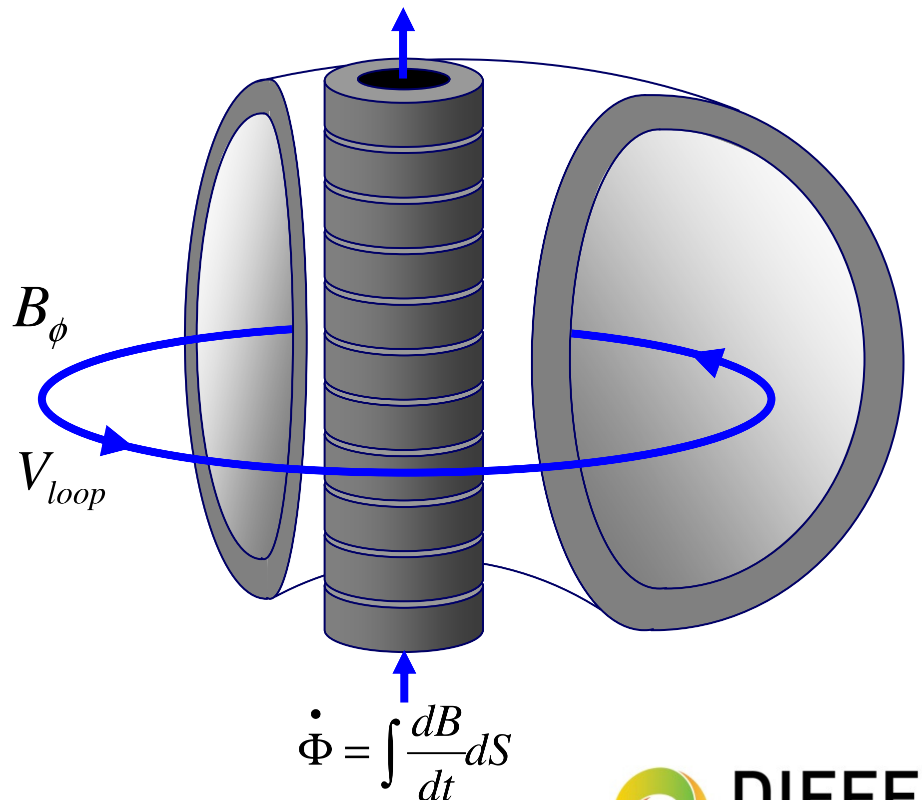
Motivation for these studies

- Compare the general breakdown characterization with recently improved models on error fields dynamics and plasma burn-through.
- ITER will have lower electric fields available for breakdown (<0.35V/m) than most present devices (~1V/m).
- The recent installation of a full metal, ITER-like wall (ILW) provided the opportunity to study the impact of the plasma-facing materials on breakdown.

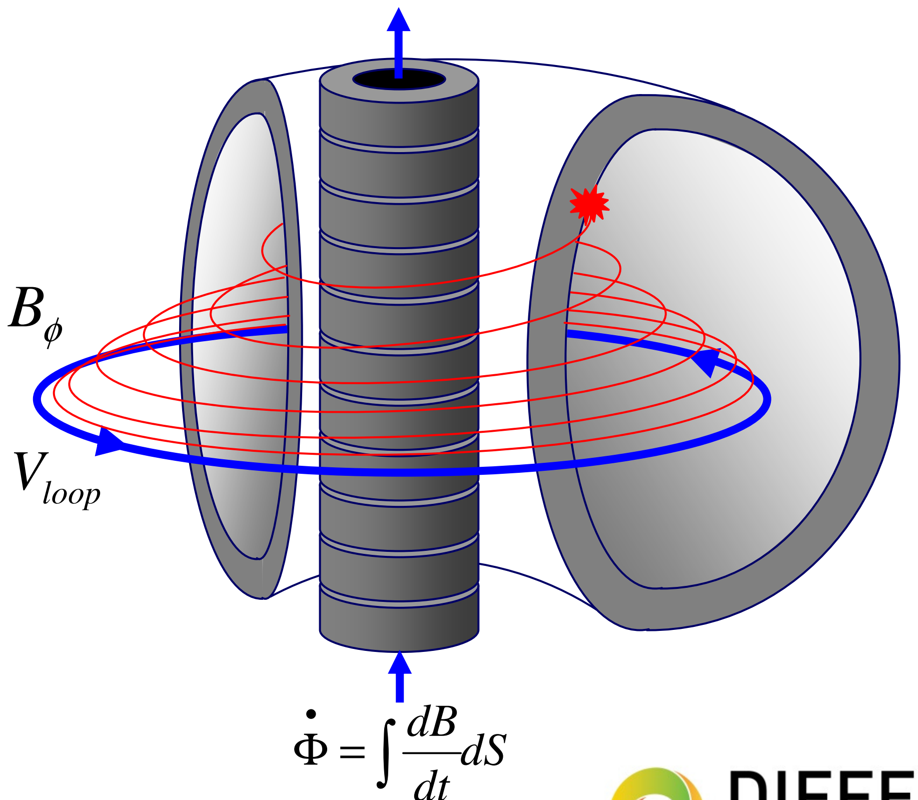
Plasma breakdown

- Plasma can be initiated in a Tokamak, by applying a toroidal voltage V_{loop} via transformer action.
- This starts with a Townsend avalanche process:
  - main ionization process due to collisions between atoms and electrons accelerated in the electric field.



Plasma breakdown

- Direct electron losses affect the avalanche process.
  - ❖ Connection length *L* to the wall needs to be long enough.
  - ❖ Poloidal error fields need to be small ➔ pure toroidal magnetic field.



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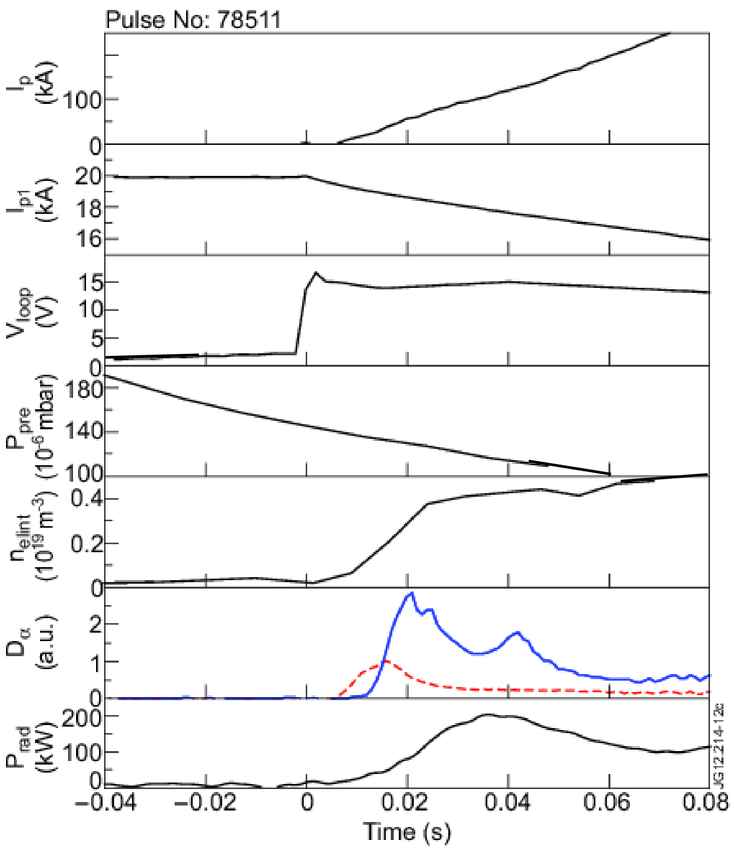
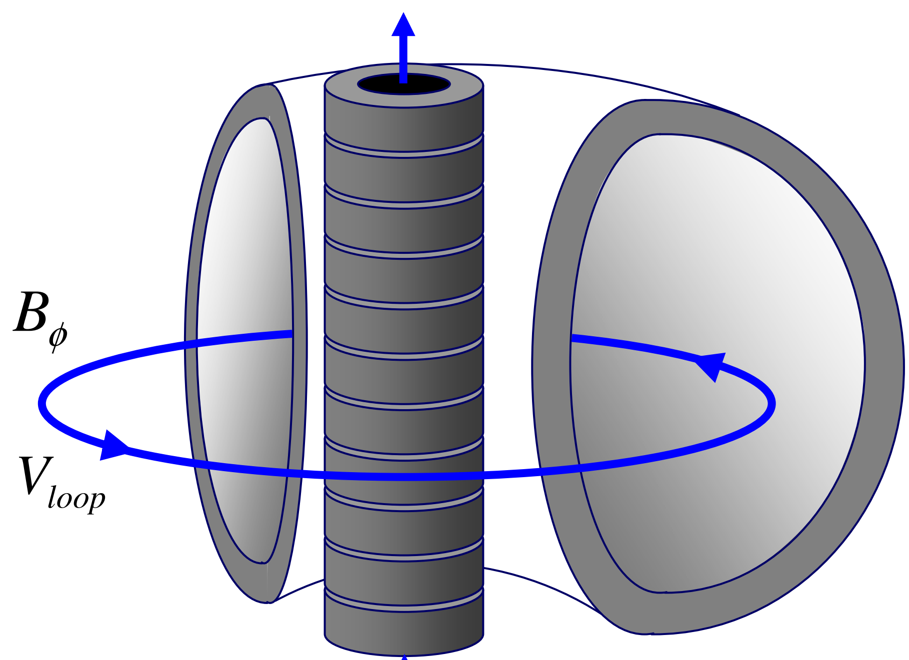
Plasma breakdown

- When the ionization fraction increases the gas will start to behave as a plasma ➔ Coulomb transition.
- Temperature still remains cold due to line-radiation losses.
  - ❖ Plasma can be sustained when it burns-through this radiation barrier.





Outline of this presentation

- Method of experimental analysis
  - A large database was used to reveal main trends and show the key characteristics of JET plasma breakdown
- The duration of the avalanche phase
  - Typical characteristics of the avalanche process are observed
  - Error field dynamics are important for low voltage breakdown
- Density dynamics and levels of impurities and radiation
  - The ILW has a profound impact on the burn-through phase
- Modeling of the plasma burn-through
  - A new breakdown model has been developed that includes PSI
- Summary of conclusions

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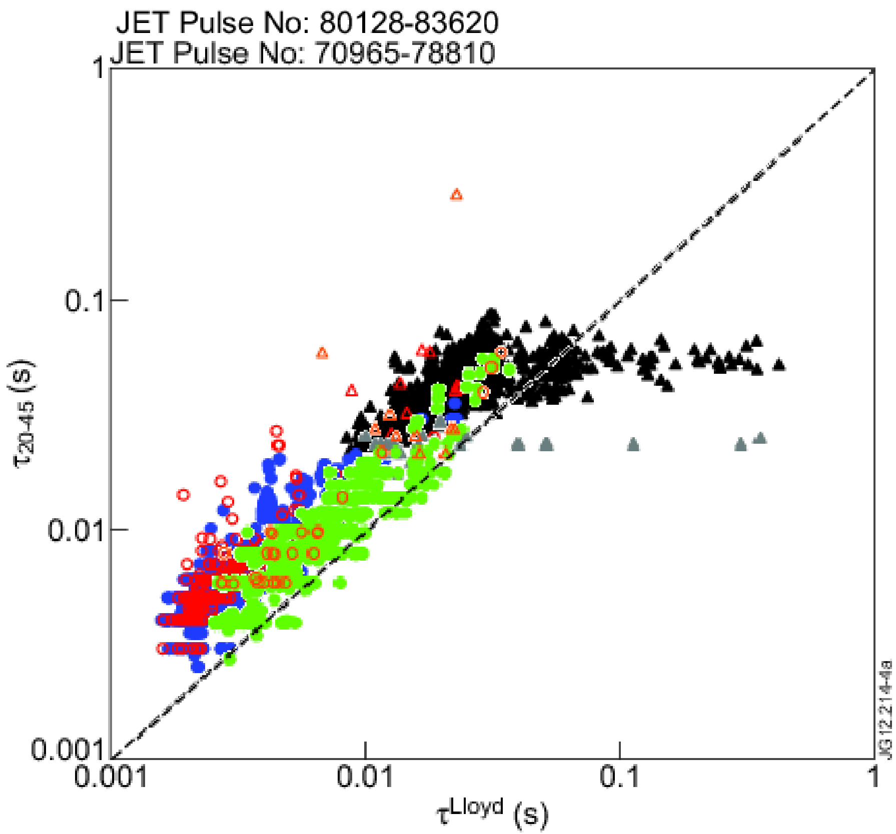
Analysis Method

- Comparing breakdown properties is not straightforward
  - Limitations of the diagnosis of the breakdown phase
  - Strong shot-to-shot variations possible (with carbon wall)

- A large database was built using **all** JET breakdown attempts since 2008:
  - C-wall (2008-2009): #70965-#78810, in total 6392 entries.
  - IL-wall (2011-2012): #80128-#83620, in total 2793 entries.

- The database reveals main trends and show the key characteristics of JET plasma breakdown that can be compared for the two operation periods

- The duration of the avalanche phase can be compared by the theoretical prediction[1]: $\tau_{avalanche} \sim \dfrac{41}{v_{De}(\alpha - L^{-1})}$



Carbon wall
- ● Mode D ('high voltage')
- ○ Failed mode D
- ▲ Mode B ('low voltage')
- △ Failed mode B

ITER-like wall (ILW)
- ● Mode D ('high voltage')
- ○ Failed mode D
- ▲ Mode B ('low voltage')
- △ Failed mode B

[1] B. Lloyd, et al., Nucl. Fusion (1991) 2031

How to determine L?

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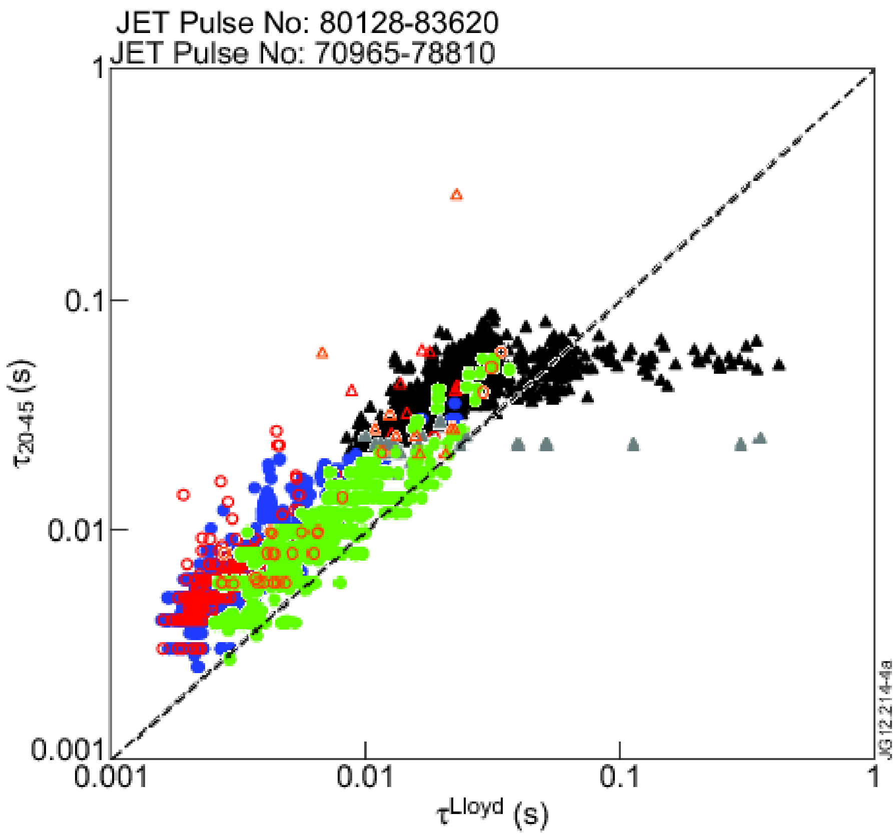

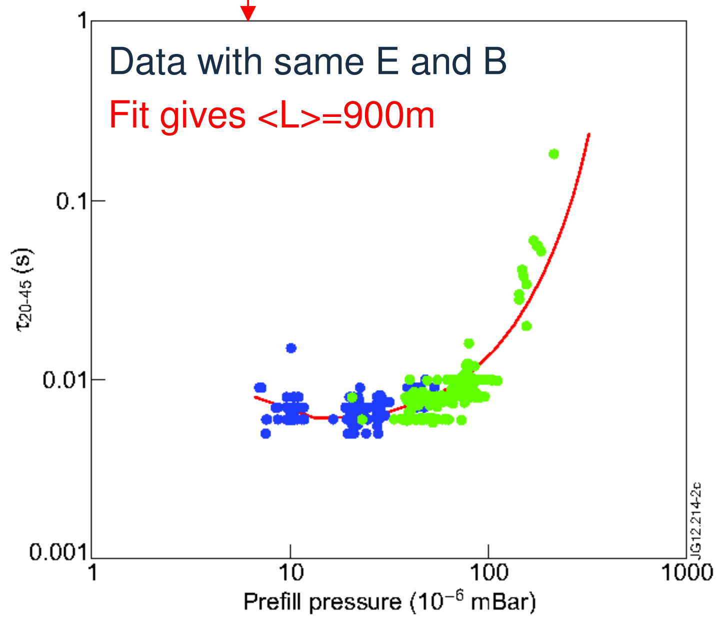

[1] B. Lloyd, et al., Nucl. Fusion (1991) 2031

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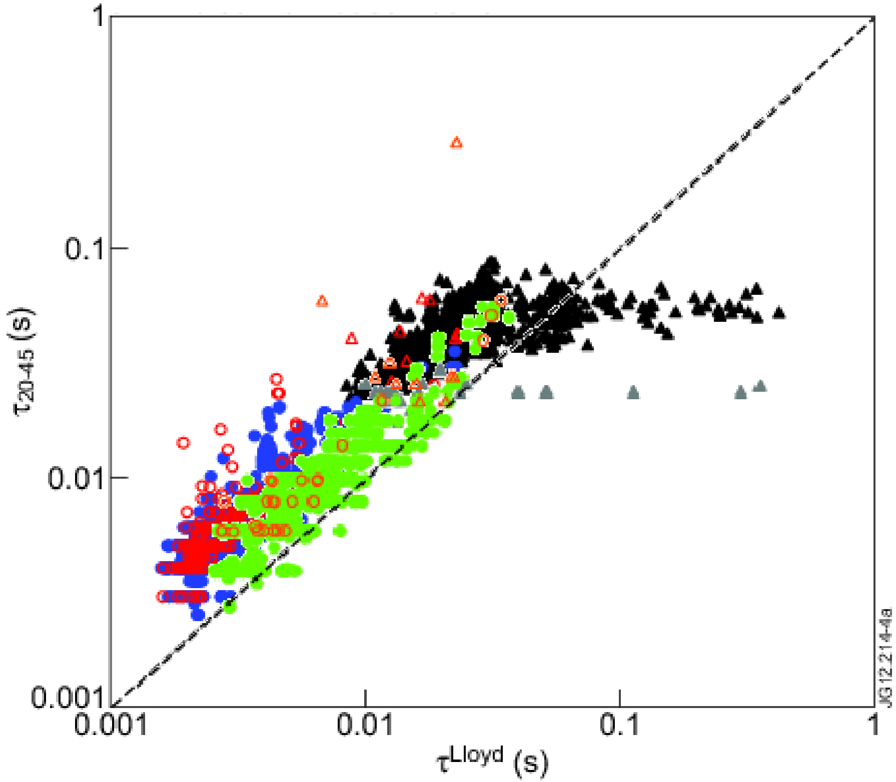
Eddy currents in passive structures

- *L* is determined by the toroidal field and the poloidal error field set by the surrounding poloidal field coils
  - ❖ The comparison fails for low voltage JET breakdown, for which the error field is underestimated due to the impact of eddy currents that are induced in passive structures around the plasma



Without scaling of L with E

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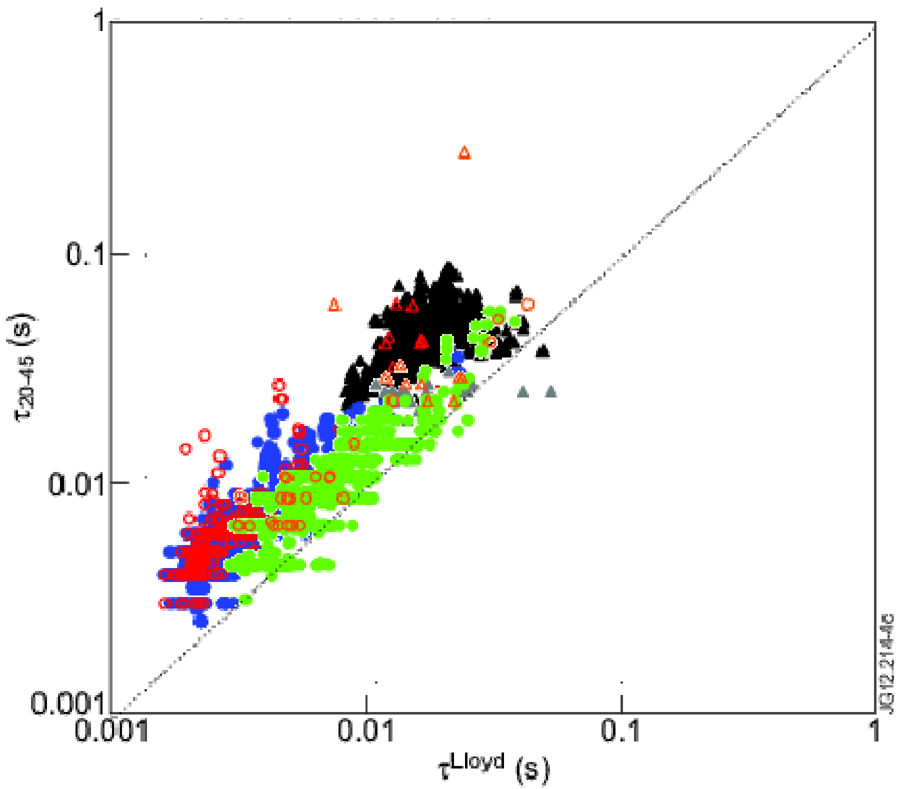
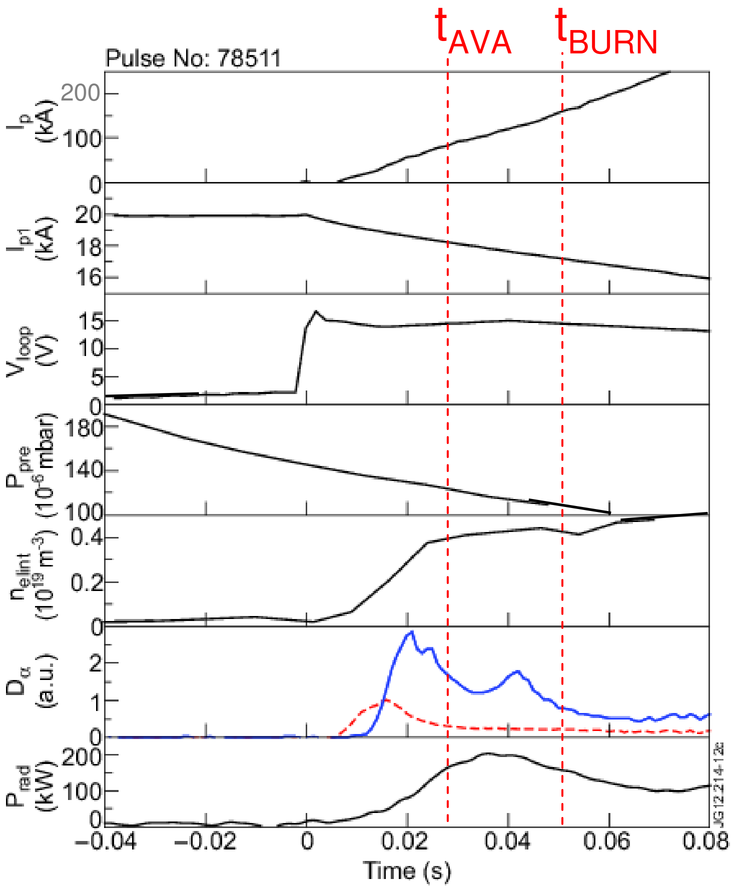


Including scaling of L with E

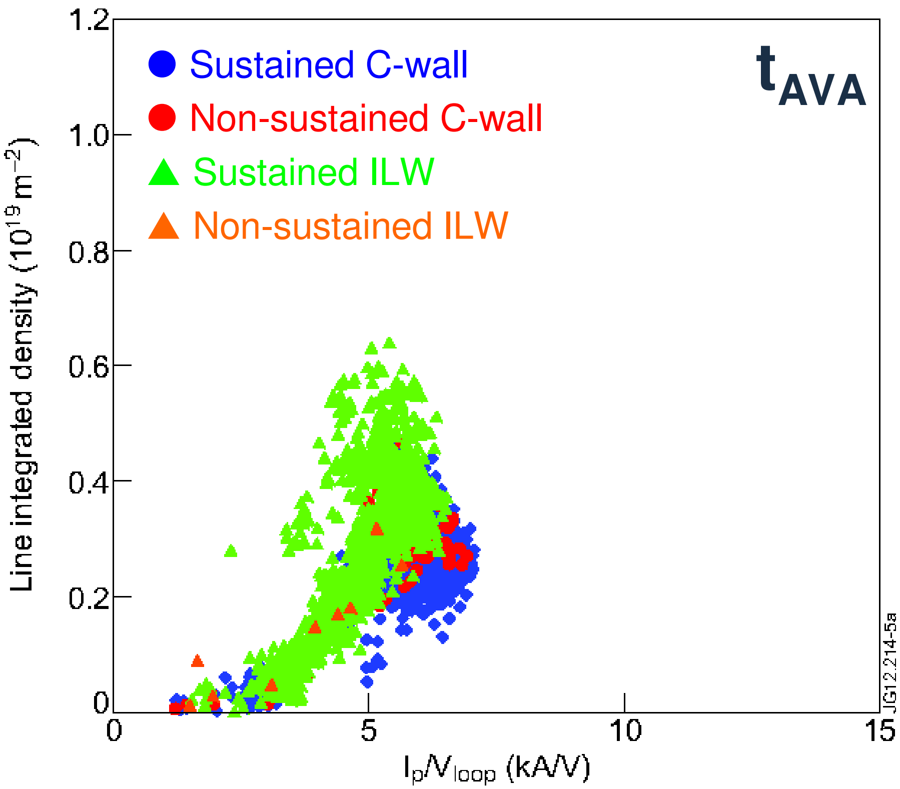
Breakdown dynamics

- For a subset with similar E_o~0.8V/m (V_{loop}~12V), compare data from two different times:
  - At the end of the avalanche time (t_{AVA}=31ms).
  - In the burn-through phase (t_{BURN}=51ms).



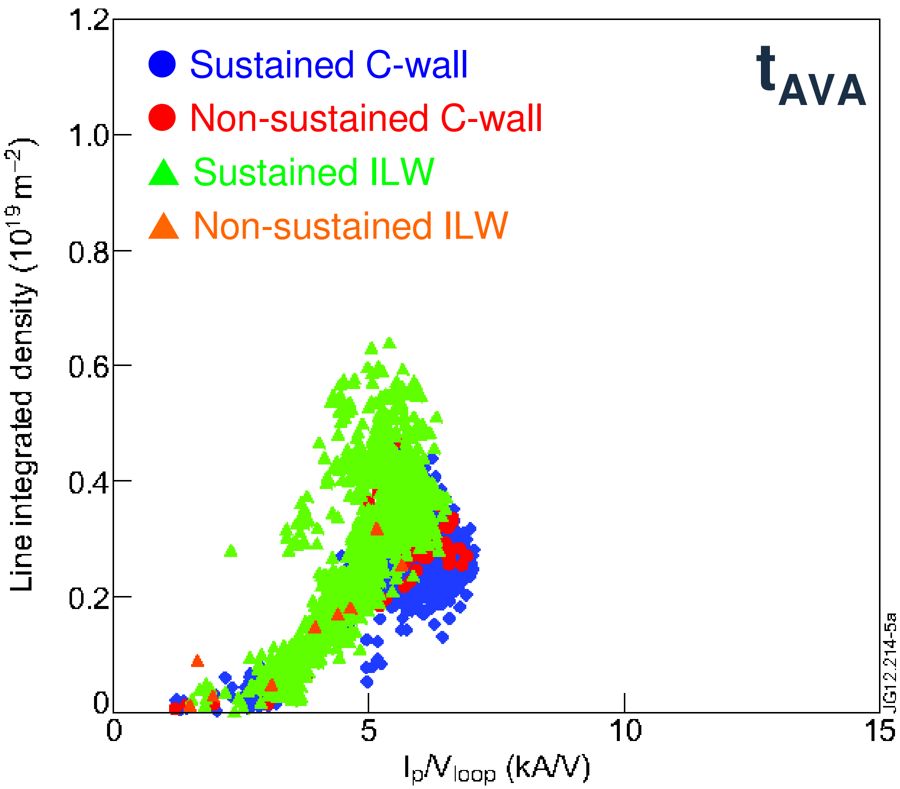
Development of density and current

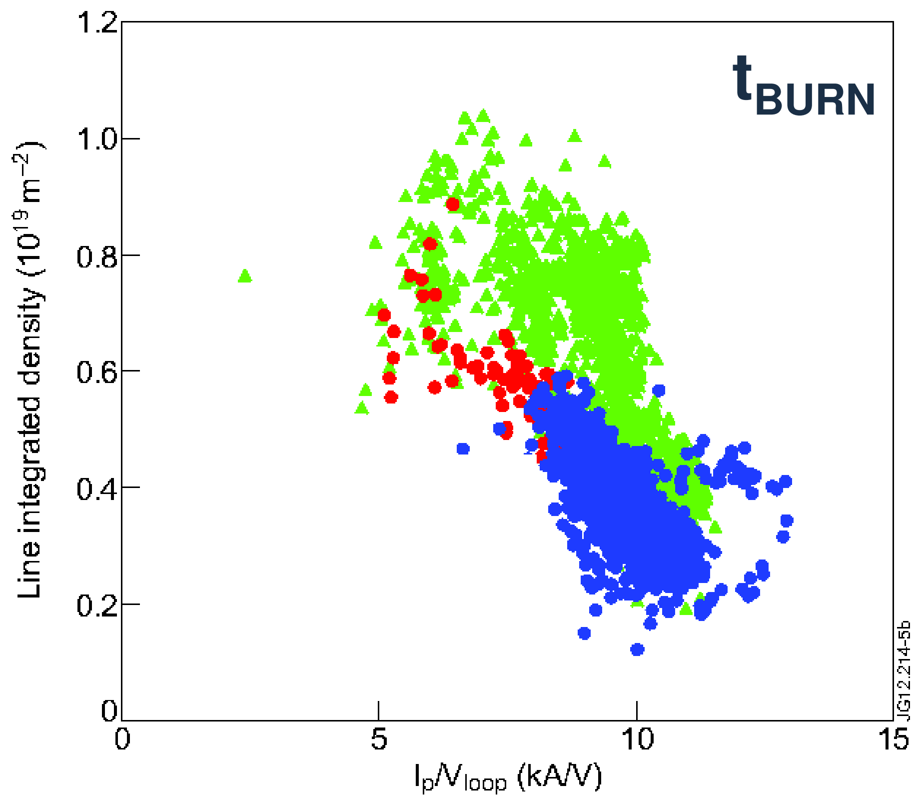
- At the end of the avalanche phase (t_{AVA})
  - Higher current ➔ higher density (i.e. avalanche characteristic)
  - No difference between failed/good and C-wall/ILW cases



Development of density and current

- In the burn-through phase (t_2)
  - Current scales inversely with density (or as T_e^{α} ➔ Spitzer?)
  - Between t_{AVA} and t_{BURN} ➔ Coulomb transition
  - Different groups for failed/good and C-wall/ILW





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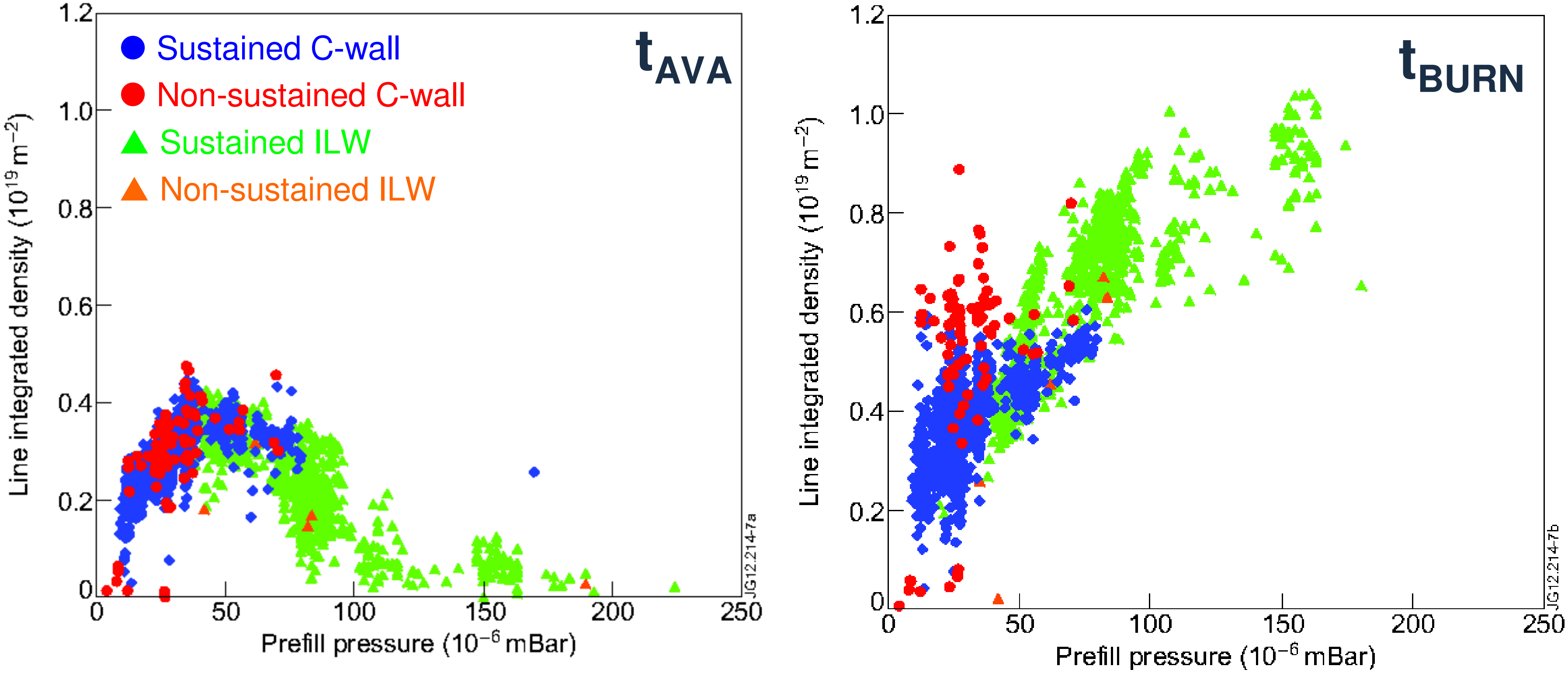
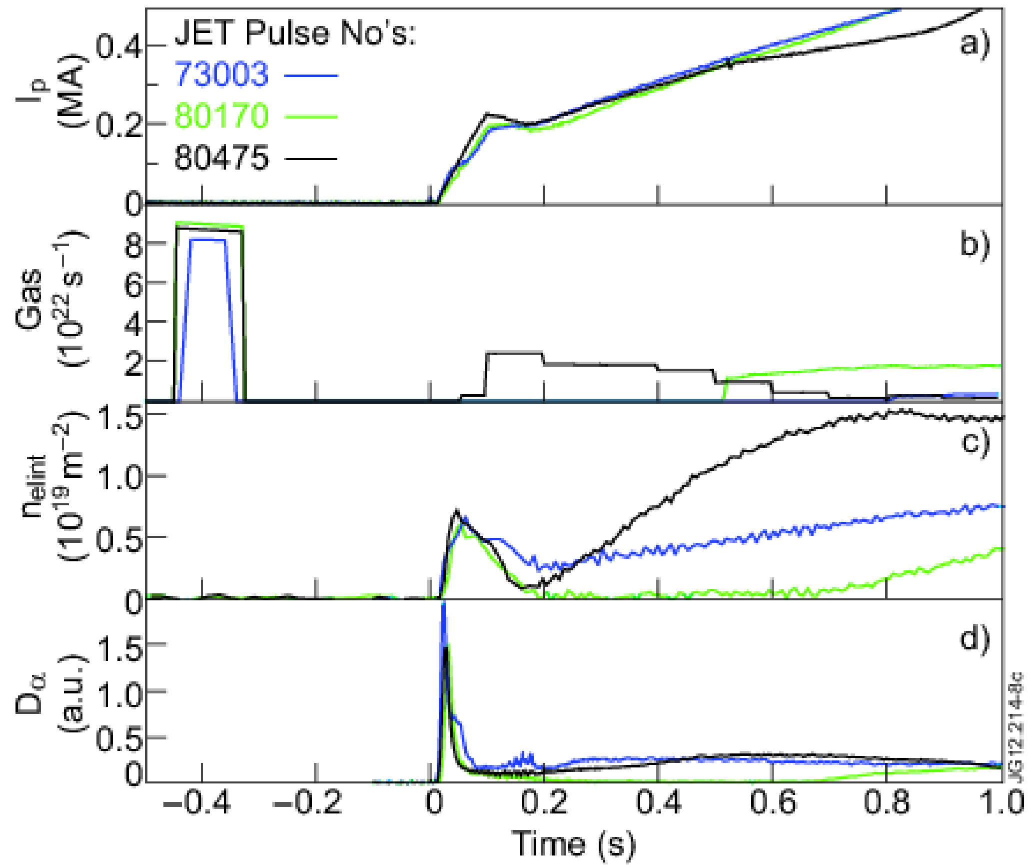
Where do the particles come from?

- Density at t_{AVA} determined by pre-fill (pressure)
  - Avalanche slower ➔ lower density at t_{AVA}
- Density at t_{BURN} scales with pre-fill pressure + extra
  - Carbon wall cases show additional 'fueling' ➔ from wall (?)

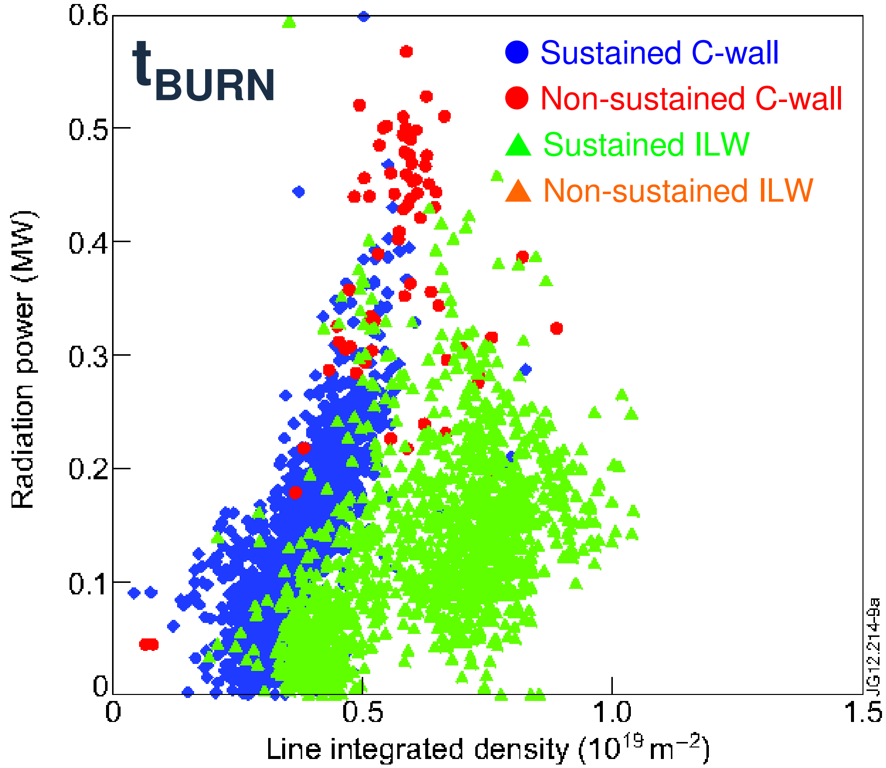


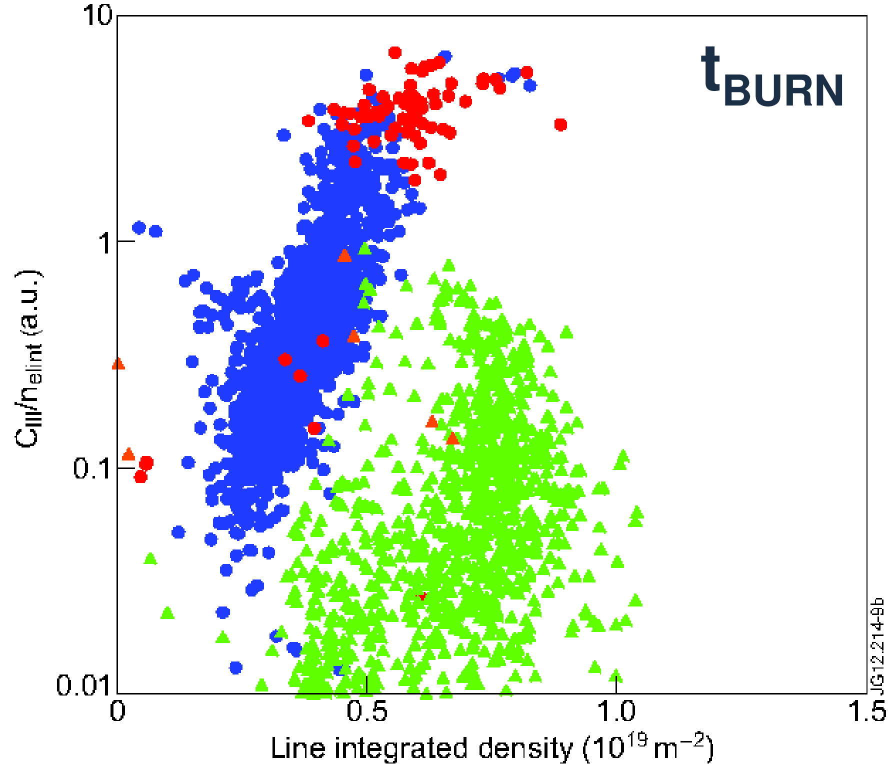
Density behaviour with ILW

- With the ILW gas fuelling and density feedback had to start directly following the breakdown phase in order to avoid to low density
  - ❖ With the C-wall wall recycling could maintain the density



- For C-wall: relation between, density, *C* content and radiation
- For ILW: much lower radiation (and *C* content)
  - No non-sustained breakdowns due to de-conditioning events with ILW
  - Radiation lower (except for *N* seeding experiments)





- No trends were found with *O* or *Ne* levels

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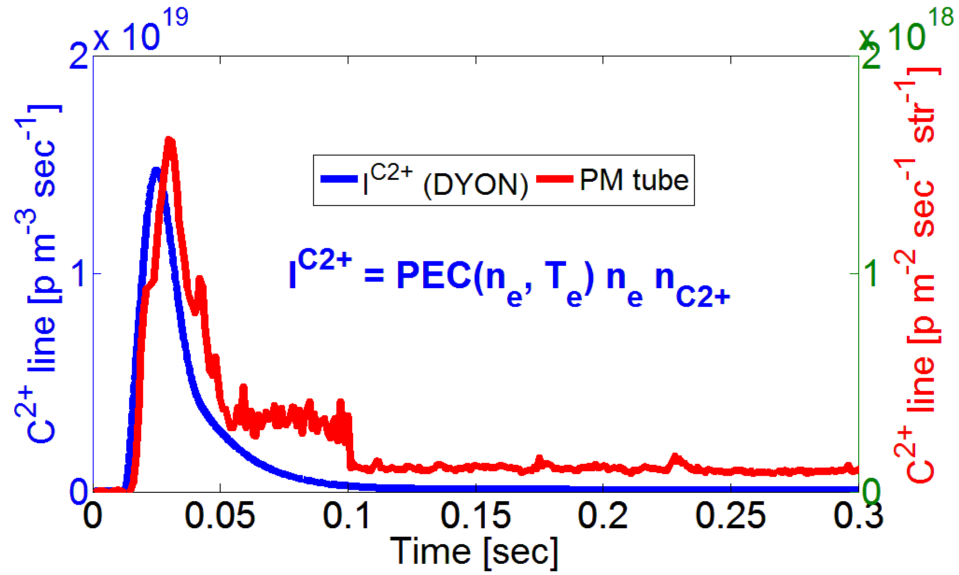
Modeling of PSI in the burn-through

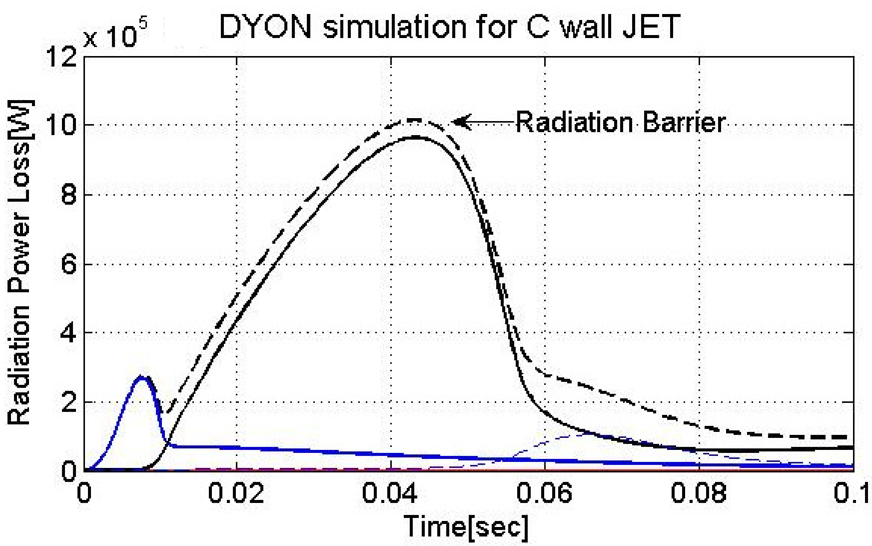
- A new model for the plasma burn-through (DYON code)[1].
  - Impurity levels during the breakdown are self-consistently determined by the plasma-surface interactions (PSI) in this code.
    - Parallel transport according to *L* + perpendicular Bohm diffusion
    - A dynamic *L* model assuming eddy currents in passive structures
    - Assumes an exponential change of D recycling
    - Calculate impurity content via chemical and physical sputtering
    - Neutral screening effects per particle species
    - Validation using JET data

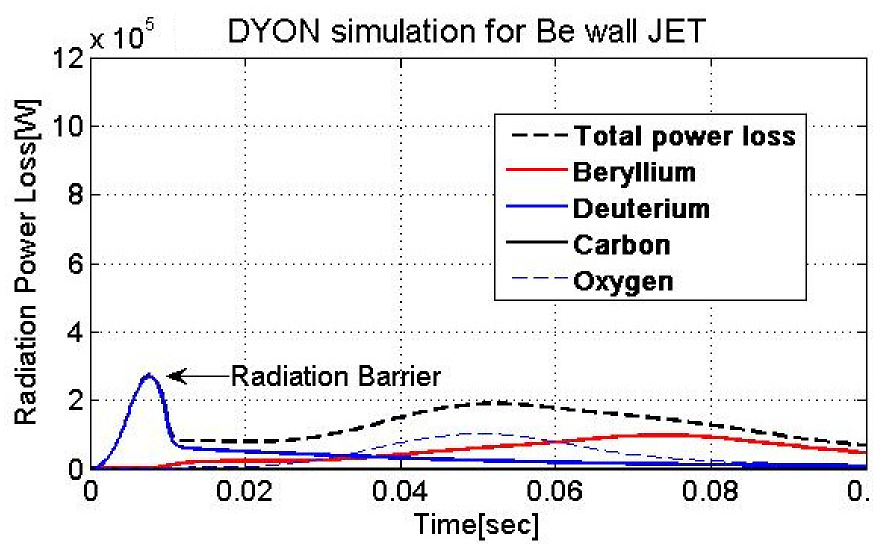


[1] H.T. Kim, Nucl. Fusion **52** (2012) 103016

Modeling of C and ILW breakdown

- A new model for the plasma burn-through (DYON code)[1].
  - For C-wall ➔ Chemical sputtering increases carbon content which dominates the radiation and burn-through
  - For ILW ➔ Physical sputtering increases the *Be* content, but *D* burn-through is sufficient to overcome the total radiation barrier.





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Conclusions

- This study clearly showed some key characteristics of different breakdown phases
  - ❖ Avalanche duration, Coulomb transition, density dynamics, etc.
  - ❖ A clearer picture of JET breakdown has been obtained
- The avalanche phase:
  - ❖ **Not** affected by the wall material and dominated by the pre-fill gas, electric field and value of the connection length (error field)
  - ❖ Eddy current dynamics impact on low voltage JET breakdown
  - ❖ ITER breakdown voltages (0.3V/m) achieved with the ILW
- The burn-through phase:
  - ❖ **Strongly** affected by the change wall material
  - ❖ Breakdown with the ILW is more robust (no burn-through failures)
  - ❖ Even after disruptions with ILW no additional condition required
  - ❖ Confirmed by the new burn-through model that includes PSI
- Poster ➔ Tomorrow morning